Use of open loop scrubbers in Gulf of Finland

Assesment of possible impact of scrubber wash waters to marine environment and evaluation of different alternatives

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Abstract

This is a study on the effect of open loop scrubbers´ wash water to the marine environment in the Gulf of Finland. The objective is to analyze the possible impact, if the use of open loop scrubbers becomes more common.

This thesis consists of theory and research. In the theory section the basic principle and the legal framework regarding to the use of scrubbers is explained. Research section focuses on the environmental issues and possible solutions and is based on literary research. The research section assesses the total emissions in a scenario where all ships were using open loop scrubbers, and these values are compared to water quality standards and areas capacity to manage this type of waste water.

This thesis was successful and shows that the wash water emissions don´t cause a threat to the environment in Gulf of Finland.

Language: English Key words: scrubber, sulphur, Baltic Sea

Table of contents

1 Glossary

AA-EQS: annual average EQS

AIS: automatic identification system

BOD: biological oxygen demand

COD: chemical oxygen demand

ECA: emission control area

EQS: environmental quality standard

FNU: formazin nephelometric unit

HELCOM: Baltic Marine Environment Protection Commission – Helsinki Commission

IMO: International Maritime Organization

LNG: liquefied natural gas

MARPOL: The International Convention for the Prevention of Pollution from Ships

MDO: marine diesel oil

MGO: marine gas oil

NOx: nitrogen oxides

NTU: nephelometric turbidity unit

PAH: polycyclic aromatic hydrocarbon

TSS: Traffic separation scheme

2 Introduction

Ever since air pollution from ships first became regulated in MARPOL in 1997, there has been a need for lowering the amount of harmful substances in exhaust gases. IMO introduced emission control areas (ECAs) to Baltic Sea and coast of North-America in 2005. In these areas the amount of sulphur in the fuel was limited 2005 to 1,5%, 2010 to 1,0% and later to 0,1% in 2015.

These new regulations forced the ship owners to use more expensive low sulphur fuels, like low sulphur heavy fuel oil (HFO), marine diesel oil (MDO) and marine gas oil (MGO). The other option is to equip the vessel with an exhaust gas cleaning system, of which the open loop scrubber was the first in the commercial market. This type of system uses the natural alkalinity of sea water to clean the sulphur and some particular matter from the exhaust gas, pumping them to sea afterwards. (American Bureau of Shipping, 2018)

The wastewater contains close to 100% of sulphur oxides from the exhaust gas. In the open loop scrubber it reacts with sea water, and the result is sulphurous acid, which is then released to the sea. Ocean acidification is a known issue, caused by the increased CO_2 emissions. This study will evaluate scrubber´s possible contribution to that.

2.1 Objective

The objective of this study is to find out the possible environmental effect of exhaust gas cleaning waste water. I will assess what possibly harmful substances and in how large quantities go overboard, how this is monitored and what is the legal framework. I will also discuss the expected effects of those substances to environment, and options for open loop scrubbers in environmental aspect.

2.2 Research methodology

To evaluate the maximum possible impact on environment a scenario is used, where all vessels would use open loop scrubbers. The base for this was results from a study “Assessment of possible impacts of scrubber water discharges on the marine environment” by Danish Ministry of Environment, Environmental Protection Agency. The results were first compared with several similar studies for credibility. These results were chosen for this study since it was the only study with all necessary values. Combining these results with HELCOM data for total fuel consumption in Gulf of Finland values for total emissions were calculated. The environmental effect of these theoretical emissions was evaluated by comparing them to current emission levels from other sources, and for the acid neutralizing capacity of riverine input to Gulf of Finland.

These methods were chosen for this study to get the results in a simple way without need to use complicated models for calculating the final concentrations in study area. This was not necessary due to the insignificance of the emissions described in this study.

3 Background

3.1 IMO regulations

International Maritime Organization (IMO) has been trying to reduce the harmful impact of shipping since 1960s. The MARPOL convention, convened in 1973, works as the base for environmental protection in the industry. The convention was modified, and annex VI was added 1997, covering emissions to air. (International Maritime Organization, 2001)

In MARPOL annex VI sulphur content of any fuel used onboard was limited to 4,5%, and in Baltic Sea area this value was lowered to 1,5%. Higher concentrations of sulphur were however allowed, if an approved exhaust cleaning system was used. Waste streams of these systems were prohibited to be discharged into enclosed ports and similar parts of waterways, unless it could be documented harmless. The sulpur content of fuel was also required to be documented by the supplier. (International Maritime Organization, 2001)

New amendments were adopted to annex VI on 15 July 2011. The emission regulations were strictly tightened. The nitrogen oxides (NOx) emissions were regulated to new built vessels in two steps; first for vessels built after 1.1.2011 and then tighter regulations for vessels built after 1.1.2016. (MARPOL Annex VI 13.3-5)

Also the amount of sulphur contents allowed was lowered to 3,5% worldwide from 1.1.2012 and will be lowered to 0,5% from 1.1.2020. In ECA:s like Baltic Sea, the limit was lowered first to 1,0% after 1.1.2010 and to 0,1% from 1.1.2015. (MARPOL Annex VI 14.1-4) The Figure 1 below indicates the reduction in allowed sulphur amounts.

Figure 1, Maximum sulphur content allowed in fuel by MARPOL

3.1.1 Option for low sulphur fuel

Rule 4 of MARPOL annex VI also gives option for low sulphur fuel stating, that with the approval of Administration, the use of an alternative compliance method at least as effective in terms of emission reductions as that required, is acceptable. More specific regulations for performance of such systems are stated in the MEPC resolution 259(68) adopted on 15 May 2015.

3.1.2 Emissions using EGC

Sulphur content is exhaust gases is measured in SO_2 (ppm)/CO_2 (%v/v), and corresponding limits in exhaust gases compared to fuel oil sulphur contents are stated in the table 1.

Table 1 Corresponding sulphur contents of fuel oil and exhaust gas ((International Maritime Organization, 2015)

Fuel oil sulphur content (% m/m)	Ratio emission SO2(ppm)/CO2(% v/v)
4,5	195
3,5	151,7
1,5	65
1	43,3
0,5	21,7
0,1	4,3

Some of these systems use water for cleaning purposes, which is in often led back to the sea. Emissions to air as well as to water must be monitored. This must include pH, PAH, turbidity and temperature. Discharge water must have pH of no less than 6, and the difference between water inlet and outlet must not be more than 2 pH units at 4m distance from the discharge point, when vessel is stationary.

PAH concentration in the wash water is limited to 50 µg/L above the inlet water´s concentration. The turbidity/ suspended particular matter in wash water should be minimized and monitored. Maximum allowed turbidity is 25 FNU or 25 NTU above inlet water turbidity. This may however be exceeded for short periods of time.

EGC systems remove also nitrates. The content of NOx in the discharge water may not exceed 12% of the nitrogen quantity of the exhaust gases, or 60mg/l normalized for 45 tons/MWh discharge rate. (MEPC.259(68))

3.2 EU regulations

European Union has implemented the IMO regulations to EU-law and has also own regulations regarding the use of open loop scrubbers. Sulphur directive (DIRECTIVE 2012/33/EU) regulates the sulphur content of fuel oil used, and also allows the use of EGCs. Some member states have prohibited the discharge of wash water inside their base line and ports. European Commission has reviewed the discharge of wash waters in item 6.C ESSF of 26.1.2016 summarizing the member state regulations and EU-law. The main conclusion is, that most countries require more studies on the subject to make decisions on their stand. (Agenda item 6.C ESSF of 26/1/2016)

EU´s water framework directive (WFD) regulates the protection of waters in EU, and any EGC:s must fulfill the WFD objectives. Many member states are concerned about some of the EGC systems possibly not filling these requirements and should therefore not be used. (Agenda item 6.C ESSF of 26/1/2016)

4 EGC systems

To meet new regulations, scrubbers have been becoming more common in both new builds and older vessels. (EGCSA, 2018)The systems have developed significantly in the past decade, and multiple options are now available.

4.1 Open-loop

The first commercial option for sulphur emission reduction was open-loop scrubber. It uses the natural alkalinity of sea water to react with the SO_x compounds in the exhaust gases.

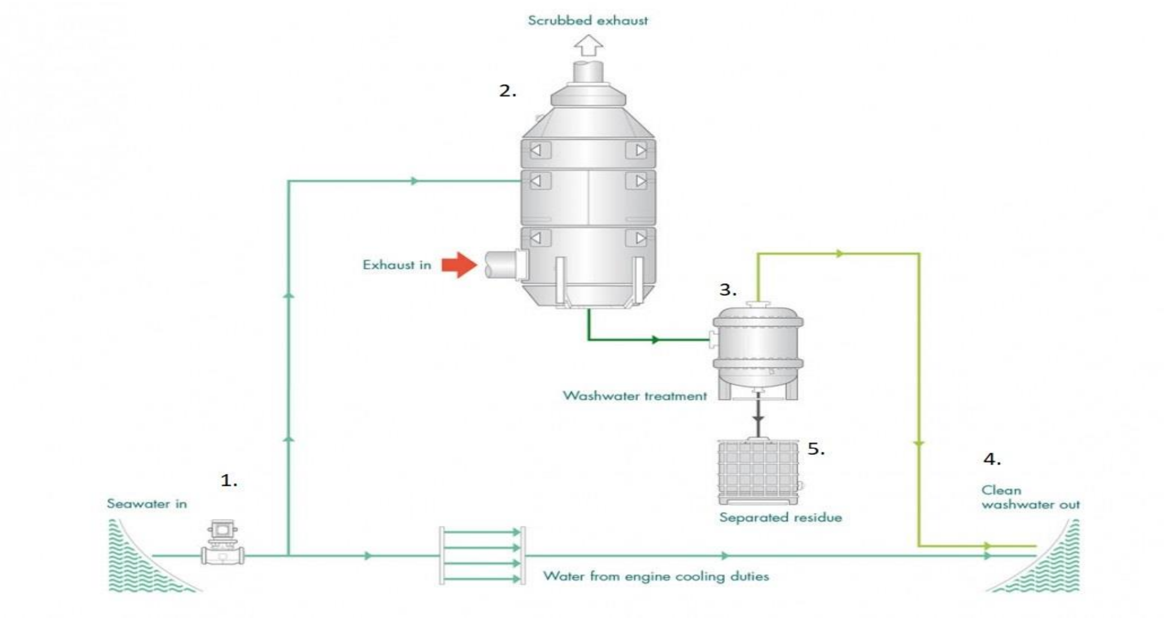

Figure 1, components of open loop scrubber ((EGCSA, 2018)

1. System takes water from the sea, which is then pumped to an exhaust gas cleaning unit (scrubber).
2. In the scrubber unit exhaust gases from the engines meets the water, which can be done by various methods, depending on the manufacturer. This dissolves sulphur oxides and particular matter.
3. In some systems after scrubber unit water goes to water treatment unit, where some particular matter is removed to a separate sludge tank.
4. Rest of the wash water is pumped back to the sea.
5. Sludge tank is emptied at ports.

Open loop scrubbers need water with natural alkalinity and are therefore designed mainly for use in ocean water. Many systems are proven to be capable of operating also in the Baltic Sea, which has a lower alkalinity, but there may be issues. The water flow may need to be increased, which means increased power consumption. One option is to add sodium hydroxide (NAOH) to the input sea water to increase the water´s acid binding capacity. This may be necessary to stay within the emission limits when trafficking in the eastern Gulf of Finland. (Irina Panasiuk, 2015)

Some systems have wash water treatment units, but the large water quantities of wash water cause difficulties. Hydro cyclone is common in open loop systems since it can manage large quantities of water. It uses centrifugal force to separate heavy solid compounds and cleaner water. After hydro cyclone there are various possibilities for processing the sludge and further remove clean water from it. (EGCSA, 2012)

Open loop system is a large unit, like all scrubber systems, which reduces cargo capacity. Unit weights 30-55t. (Loyd´s Register, 2012). (EGCSA, 2012)

4.1.1 Chemistry

There are two types of sulphur oxides in exhaust gas: SO_2 (sulphur dioxide) and SO_3 (sulphur trioxide). Most of the sulphur oxides are sulphur dioxide, and only a small amount of sulphur trioxide. The reaction with sulphur dioxide is following:

1. When water is introduced to SO_2 it reacts creating sulphurous acid and further ionizes to H^+ and bisulphite. $SO_2 + H_2O \leftrightarrow H_2SO_3 \leftrightarrow H^+ + HSO_3^-$

2. Bisulphite further ionizes to sulphite and H^+. $HSO_3^- \leftrightarrow H^+ + SO_3^{2-}$

3. Sulphite reacts with oxygen resulting suphate. $SO_3^{2-} + {}^1/_2O_2 \rightarrow SO_4^{2-}$

Reaction with sulphur trioxide:

1. Sulphur trioxide and water react creating sulphuric acid. $SO_3 + H_2O \rightarrow H_2SO_4$

2. Sulphuric acid further reacts with water resulting hydrogen sulphate and hydronium. $H_2SO_4 + H_2O \rightarrow HSO_4^- + H_3O^+$

3. Hydrogen sulphate and water react react resulting sulphate and hydronium. $HSO_4^- + H_2O \rightarrow SO_4^{2-} + H_3O^+$

In both reactions the result is strongly acidic wash water, which is then neutralized by the sea waters natural buffering capacity, mainly bicarbonate (HCO_3^-). The unit requires a large amount of power, since the water flow required is approximately $45m^3$/ MWh, for sulphur content of 2,7% in the fuel. The estimated operating cost of open loop system is 3% of investment cost, including power consumption and maintenance (Jesper Kjølholt, 2012). (EGCSA, 2012)

4.1.2 Inert gas systems

Open loop scrubbers have been common onboard tankers for a long time. They are used to create non-combustible gas for tanks to ensure safe tank environment. These systems mainly work using the open loop principle, but instead of main engines, the exhaust gases are taken from boilers or auxiliary engines. Exhaust from boilers is often preferred in order to fulfill the requirements for low oxygen content. The systems are smaller in size, but the demands for cooling are much higher, and therefore water consumption is larger.(MSC.367(93)), (International Maritime Organization, 1990) Possible issue with these systems is that they are often used in ports for long periods of time, so local affects to environment may be significant.

4.2 Closed loop

Closed loop system uses fresh water for exhaust gas cleaning, with added chemicals, most commonly sodium hydroxide (NaOH). The system is similar to open loop, but instead of using sea water, fresh water is circulated in the system, which makes it independent of seawaters alkalinity. Therefore, closed loop systems are recommended solution for areas with lower sea water alkalinity. (Wärtsilä, 2018)

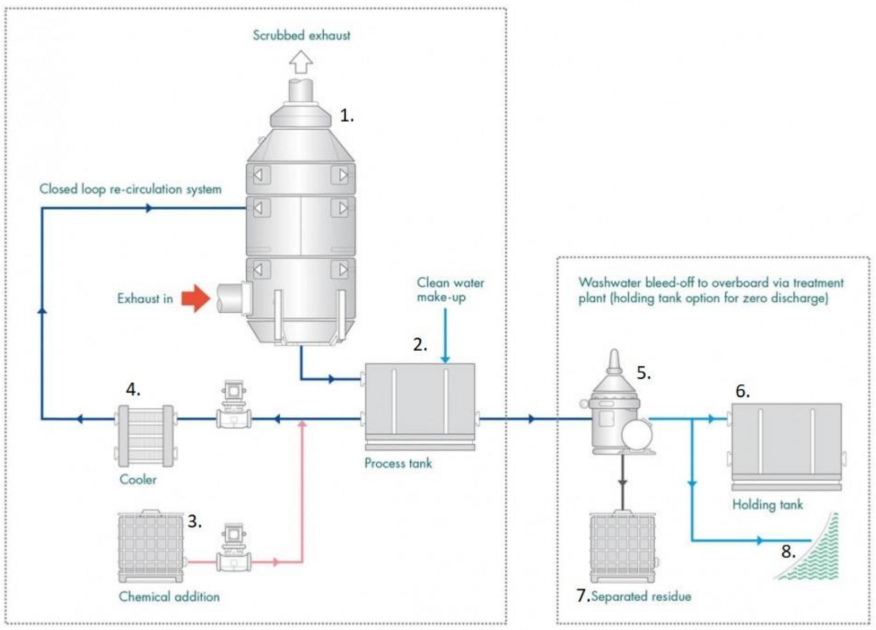

Figure 2, closed loop system (EGCSA, 2018)

General layout of closed loop system can be seen from figure 2.

1. Scrubber unit is similar to ones in open loop systems. Water is used to reduce particular matter and sulphur oxides.

2. Water is circulated through process tank. From the bottom of the tank some water with particular matter is taken for further processing and in some cases discharge.

3. Sodium hydroxide is added to maintain the reactions in scrubber unit.

4. Water heats up when it´s in contact with the hot exhaust gases. A sea water cooler is used to maintain desired temperature.

5. Water treatment unit is used to separate particular matter from the bled off water.

6. Holding tank is used in zero discharge option.

7. Sludge tank is used for storaging particular matter and is emptied in ports.

8. In open sea bled off water is normally discharged to sea. The amount of bled of water is normally 0,1-0,3 m^3/MW h.

(EGCSA, 2012), (Wärtsilä, 2018)

4.2.1 Chemistry

Sodium hydroxide is added as a water solution ($Na^+ + OH^-$) to the system, and the reactions with water and sulphur dioxide are following:

1. Sodium and hydroxide ions react with sulphur dioxide, resulting sodium bisulphite (aq) $Na^+ + OH^- + SO_2 \rightarrow NaHSO_3$

2. Sodium and hydroxide ions react with sulphur dioxide, resulting sodium sulphite (aq) $2Na^+ + 2OH^- + SO_2 \rightarrow Na_2SO_3 + H_2O$

3. Sodium and hydroxide ions react with sulphur dioxide and oxygen, resulting sodium sulphate (aq) $2Na^+ + 2OH^- + SO_2 + {}^1/_2\ O_2 \rightarrow Na_2SO_4 + H_2O$

Reaction with sulphur trioxide, sodium hydroxide and water is following:

1. Sulphur trioxide reacts with water to sulphuric acid. $SO_3 + H_2O \rightarrow H_2SO_4$

2. Sodium hydroxide reacts with sulphuric acid to sodium suphate and water. $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

The added sodium hydroxide allows the systems to work on a lower flow rate of approximately $20m^3$/MW h. It reduces the power consumption. In the other hand system requires water for cooling purposes, sodium hydroxide storage and tank capacity for bled of water. The weight of the system is 30-55t (Loyd´s Register, 2012). (EGCSA, 2012), (Eelco den Boer, 2015)

4.3 Alternative systems

4.3.1 Hybrid

Hybrid scrubbers are a combination of open- and closed loop systems. They can be operated in both sea water and fresh water mode and are designed for vessels that traffic in oceans and waters with low alkalinity. (Wärtsilä, 2018) The weight of the system is 30-55t (Loyd´s Register, 2012). The systems are however more expensive and need slightly more space.

4.3.2 Dry scrubber

The dry scrubber technology uses granulated hydrated lime (calcium hydroxide – $Ca(OH)_2$) to remove sulphur compounds. The exhaust flow is directed through a packed bed of granulate in horizontal direction. Fresh granulate is added from the top, and reacted waste is collected from the bottom using an automatic system. Similar reduction levels of sulphur oxides can be achieved compared to wet scrubbers. Dry scrubber units are larger than wet systems, approximately 200t, but they don´t have any emissions to sea. (Loyd´s Register, 2012)

4.3.2.1 Chemistry

A chemisorption reaction sulphur compounds of the exhaust gases react with the calcium hydroxide, creating a stable compound. To maximize reaction surface the calcium hydroxide is in granulate form with size range varying from 2mm to 8mm. (Loyd´s Register, 2012) (EGCSA, 2012) Following reaction happens with sulphur dioxide:

1. Sulphur dioxide reacts with calcium hydroxide, resulting water and calcium sulphite. $SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$

2. Calcium sulphate further reacts with oxygen to calcium sulphate. $2\ Ca(OH)_2 + O_2 \rightarrow 2CaSO_4$

3. Calcium sulphate reacts with water, and the final product is calcium sulphate dihydrate – gypsum. $CaSO_4 + 2H_2O \rightarrow CaSO_4{*}2H_2O$

Reaction with sulphur trioxide is following:

1. Sulphur trioxide reacts with calcium hydroxide resulting calcium sulphate dihydrate – gypsum. $SO_3 + Ca(OH)_2 + H_2O \rightarrow CaSO_4{*}2H_2O$

   (EGCSA, 2012) (Loyd´s Register, 2012)

4.3.3 Other alternatives

4.3.3.1 LNG

In recent years LNG (liquifiedd natural gas) has became a considerable alternative for scrubbers. It is a strong option especially for new builds, but more difficult as a retrofit. LNG is one of the most ecological fuel types available for shipping. It is also relatively cheap. The largest issues are the high cost of the systems and availability of LNG.

4.3.3.2 Low sulphur fuels

Different fuel suppliers offer a variety of low sulphur fuels. Marine diesel oil (MDO) is a mixture of distillates and some HFO, available with sulphur content varying from 0,1 to 1,5%. Marine gas oil (MGO) is also a mixture of distillates, available with sulphur contents from 0,1% to 1,0%. These lighter fuels don´t need to be heated during storage. Heavy fuel oil (HFO) is also available with sulphur content of 0,1% and therefore can be used in ECA areas. (American Bureau of Shipping, 2018)

These cleaner and more processed fuels are a common option in smaller vessels, where large scrubber systems cannot be fitted. Using these fuels is common also in older vessels, where large investments may not be profitable.

5 Alkalinity

Alkalinity is a measure that describes waters total acid-binding capacity. It indicates how many hydrogen (H^+) ions the water can neutralize. Most of this capacity is caused by water´s bicarbonate (HCO_3^-) and carbonate (CO_3^-) concentration. It is a key factor in the pH balance, basically indicating how much acid can be added without causing significant change to pH. The total alkalinity (A_T) is calculated by adding the all substances that can bind acids, and then subtracting acid compounds. (Jens Daniel Muller, 2016)

5.1 Wash water neutralization

As mentioned earlier, discharged wash water contains strong acids, which are then neutralized by the water´s alkalinity. The excess of hydrogen ions combines with carbonate ions resulting bicarbonate. That reduces the hydrogen ion activity, and therefore limits the effect on pH. Bicarbonate also combines with hydrogen ions, resulting carbonic acid (H_2CO_3) which further reacts to water and carbon dioxide (aq).

CO_2 (aq) + H2O $\leftrightarrow H_2CO_3 \leftrightarrow H^+$ + HCO3$^- \leftrightarrow H^+ + CO_3^{2-}$

When all alkalinity is used, hydrogen ion concentration will rise which means a change in pH.

(EGCSA, 2012)

6 Ocean acidification

Ocean acidification is a worldwide phenomenon, caused mainly by the increased carbon dioxide concentration in air. More carbon dioxide in air means more dissolved carbon dioxide in water, which pushes the reaction described in 5.1 towards the middle, increasing the hydrogen concentration. The oceans´ average pH has lowered by 0.1 units since the industrialization started, which means ca. 25% increase in acidity. It is estimated that in the next 100 years pH will fall 0.35 units more due to the increased carbon dioxide emissions and the lowered CO_2 binding capacity of the planet. (Havenhand, 2012) (Scott C. Doney, 2018)

There is a limited amount of studies done regarding the effects of ocean acidification to nature. In Baltic Sea the most vulnerable species known are mussels and cod in their larval stages. Many algae and plants have in the other hand had a positive impact from the phenomenon. Most Baltic Sea organisms are relatively tolerant to small changes in pH, however most of the studies have been done on short time scale, and knowledge of the subject is still highly limited. (Havenhand, 2012)

All other acids will also have an impact on ocean acidification. The possible effects of scrubber wash water will be evaluated later in this study.

7 Study area

This study focuses on Gulf of Finland, since it´s an area with dense ship traffic, relatively small water circulation and low alkalinity. The area is also relatively shallow especially in eastern parts making the total volume small, and the area more vulnerable to emissions.

7.1 Gulf of Finland

Gulf of Finland is a section of Baltic Sea. Surrounded by Estonia, Finland and Russia and in west a line from Hangöudde (22º 54´ E), Finland, to NW extreme of island of Odensholm, and a line from SE extreme of Odensholm to Spithamn Point (59º 13´ N) in Estonia. (International Hydrographic Organization, 1953)

The total volume of Gulf of Finland is 1103 km^3 (Pekka Alenius, 1998). Water exchange is limited. Inflow of fresh water from the rivers is estimated to be 115km^3 a^{-1}. Water exchange with Baltic Proper is estimated to be around 3200km^3 a^{-1}, with an inflow of 1417 km^3 and out flow of 1532 km^3. The effect of exchange water to eastern parts of the Gulf is however more complicated due to the currents in the area. (Oleg Andrejev, 2004)

7.2 Alkalinity

The alkalinity in the Baltic Sea is generally lower than in the oceans. That is a cause of the small water exchange with Atlantic Ocean, and large run-off area. Smallest alkalinity is in the northern parts of Gulf of Bothnia and eastern parts of Gulf of Finland. Highest alkalinity levels are in the south-western parts of Baltic Sea, where the water exchange with Atlantic Ocean has the greatest effect.

In Gulf of Finland alkalinity levels have large differences. In the western parts total alkalinity is around 1400 µmol L^{-1}. The amount decreases towards east, since the affect of water exchange with Baltic Proper is smaller, and low alkalinity water is coming from the rivers in the east. In most of the study area total alkalinity is around 1200 µmol L^{-1}, but in the easternmost parts alkalinity goes down to 800 µmol L^{-1} as a function of salinity, when salinity goes down to 0%. (Karol Kulinski, 2017) The fresh water coming to Gulf of Finland has a relatively high alkalinity compared to for example rivers coming to Bay of Bothnia, since the rivers flowing to Gulf of Finland have a more limestone rich drainage basins. (Sofia Hjalmarsson, 2018)

7.3 Ship traffic

Gulf of Finland has relatively intense ship traffic compared to it´s volume. Traffic separation schemes (TSS) run through the middle of the area to St. Petersburg, where large amounts of oil and other cargoes are transported. The total amount of ships using AIS crossing the line between Hanko and Estonian coast in 2013 was 38150, of which most were cargo ships and tankers (Mika Raateoja, 2016). This number is also constantly growing.

7.4 Emissions from shipping

HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission) gathers data about emissions and ship traffic in Baltic Sea using data gathered from AIS (automatic identification system). During year 2015 in Gulf of Finland total amount of 471 000t of fuel was used for main engines, and 270 000t for auxiliary engines (Lasse Johansson, 2018).

8 Study scenario

In the study scenario I use the worst possible values in terms of environmental impact. In the scenario all ships would be using the open loop system, and the sulphur content in fuel used is 3,5% which is the maximum allowed by IMO.

8.1 Substances in wash water

Open loop wash water has a low pH since it contains large quantities of acids. It also contains nitrogen, PAH:s and metals. In the table 2 below is the addition of certain substances to sea water, when it was used in an open loop system. That information has been used to calculate the total quantities entering Gulf of Finland in a case where all IMO vessels would be using open loop system. The data for substances marked as red are unreliable, and for sulphur the total quantity has been calculated for fuel with 3,5% sulphur content assuming that 100% of sulphur is captured into the wash water. Table 2 is based on the Danish Ministry of the Environment´s study on-board Ficaria Seaways, operating in open loop mode, on 2,2% sulphur HFO and 85-90% engine load.

Table 2 Total quantities of harmful substances in wash water ((Jesper Kjølholt, 2012) (Lasse Johansson, 2018)

		addition/l of wash water	Emissions/ kg of fuel burned	Baltic Sea by IMO vessels/t/year	GOF/t/year
COD	mg/l	8	2279,202	8182,3	1073,50
sulphur total					16485,00
nitrogen total	mg/l	0,44	125,356	450,0	59,04
lead	ug/l	20,8	5925,926	21,3	2,79
copper	ug/l	255	72649,573	260,8	34,22
nickel	ug/l	34,1	9715,100	34,9	4,58
vanadium	ug/l	178,2	50769,231	182,3	23,91
zinc	ug/l	442	125925,926	452,1	59,31
total hydrocarbons	ug/l	110	31339,031	112,5	14,76
PAH	ug/l	0,96	273,504	1,0	0,13
naphthalene part of total PAH	ug/l	0,48	136,752	0,5	0,06
benzoapyrene	ug/l	0,01	2,849	0,0102	0,00

The wash water test results from Ficaria Seaways were compared with wash water test results from vessels Zaandam and Pride of Kent in Table 3. Results were mostly in line, but also some differences were found. There can be many explanations for those; different fuel in use, different wash water processing if any, different engine and engine load, contaminated samples and different sampling methods.

Table 3 Wash water quality, ((Jesper Kjølholt, 2012) (United States Environmental Protection Agency Office of Wastewater Management, 2011)

	Ficaria Seaways	Zaandam	Pride of Kent
water flow m^3/h	1000	390	216
engine power	21MW	9MW	4x1,2MW
scrubber type	hybrid (open loop mode)	open loop	open loop
pH drop	2-4,1	2	1,39
temperature above intake		les than 3,5C	1,9-16,9C
COD	52mg/l	139mg/l max	
nitrate total	560ug/l	45-146ug/l	628 ug/l
suspended solids	14-15 mg/l	17 mg/l	
sulphur	870-900mg/l total sulphur	32-48,6 mg/l sulfite	2600-3052 mg/l sulphate
PAH	0,96-1,8 ug/l	100-134 ppb	3080ng/l
arsenic	<1-1,8 ug/l	81 ug/l	
chromium		22ug/l	
copper	110-260ug/l	18ug/l	37-129 ug/lintake, 32-129 out ug/l
lead	3,6-21 ug/l	0,4ug/l	18-34ug/l
nickel	9,1-43ug/l	20ug/l	34ug/l

9 Assesment of environmental impact

This section evaluates the possible impacts of the wash water and is calculated with the total emissions from table 2. The affects of sulphur is assessed with the neutralizing capacity of the water flowing to Gulf of Finland from the rivers, and other substances are compared to the current emissions from other sources and European and Finnish environmental quality standards (EQS).

9.1 Sulphur

In the study scenario the annual amount of sulphur caused by open loop systems is 10 362 t. As mentioned earlier the total volume of water entering to Gulf of Finland from the rivers is ~115 km^3 in a year, with the alkalinity of 800 µmol L^{-1}. With this information can be calculated, that the sulphur from open loop systems roughly a percent of the annual neutralizing capacity of the fresh water flowing into Gulf of Finland.

The affect to acidity even only for the entering fresh water is so insignificant, that there is no need to further evaluate the affects to the sea water´s acidity. Even if the sulphur quantities were significantly larger, the differences would be minimal compared to the acidification caused by increased CO_2 concentration in the atmosphere.

The final reaction product, sulphite, is a common compound in sea water. In the ocean a normal concentration is ~2700 mg/l, and in the in Gulf of Finland ~500 mg/l. (Ekholm, 2019) The yearly addition of sulphite would be ~0,6% of the total quantity, so the mixing with Baltic Proper would cause the rise in concentration to be irrelevant. As a reference, the Metsäfibre´s bioproduct mill has an annual 13 000 tons sulphite discharge to the river water flowing to Baltic sea, which is more than the total sulphite emissions of this study scenario. (Metsä Fibre OY, 2019)

9.2 Nitrogen

Nitrogen is one of the two main nutrients entering Baltic Sea. The primary producers of the ecosystem fix it into their biomass. When large quantities of nitrogen is available, the amount of primary producers increases rapidly, leading to rise in the quantity of secondary producers. This excess biomass uses oxygen from the water, when it decomposes, which leads to oxygen depletion especially in areas like Baltic Sea, where water exchange is limited. (Helsinki Commission, 2003)

The annual total input of nitrogen to Gulf of Finland in 2010 was ~127 000t. Riverine and point sources load make ~70% of the total nitrogen load of which ~20% is from point sources, while the remaining 30% is from atmospheric deposition (Helsinki Commission, 2003). (Helsinki Commission, 2019) The total nitrogen load from the wash water in this scenario is 59 t/a, which is less than 0,1% of the total annual input of nitrogen.

As mentioned in chapter 3.1.2, the nitrogen oxides quantity in the wash water may not exceed 12% of the quantity in exhaust gas, so most of the NO_x is let out to air, from where it will eventually partly end up to sea.

9.3 Metals

The available data for metal concentrations in the wash water was partly unreliable, but gives an overall picture of the possible quantities. Some of the metals are natural and less harmful for Baltic Sea, while some are considered as harmful substances. The most harmful metal found in wash water is lead, and the total emissions from wash waters would be ~2,8t/a for GOF. The lead quantity in the available data was however unreliable, since it appears to be more lead in the wash water for a kg of fuel burned than in the fuel itself. The existing riverine and point source input of lead for GOF for 2014 was 186,5t, meaning that even with these quantities, scrubber wash waters would have only a share of ~1,5% of the total input. (Helsinki Commission, 2018)

Metals enter Baltic Sea also via atmospheric deposition. For lead this amount was 177t in 2013. (Helsinki Commission, 2018) Metals are found also in MGO, and without scrubber it is released to atmosphere, where it finally partly ends up back to sea. Metal contents of MGO and HFO are mostly similar. The only differences are with nickel and vanadium. HFO contains four times more nickel (42 mg/kg) and more than 150 times more vanadium (150 mg/kg). (Jesper Kjølholt, 2012)

In addition to lead, nickel is the only metal with EQS, that had a rise in concentration between the scrubber water inlet and outlet. The AA-EQS (annual average concentration) is 8,6 µg/kg. (FINLEX 23.11.2006/1022 annex 1) The possible annual nickel input from wash water is ~4,6 t/a, which is ~0,05% of the AA-EQS value. This amount does not cause relevant addition to concentration even in a long run because of the water mixing.

9.4 PAH_{16}

Poly aromatic hydrocarbons are a group of permanent organic pollutants. They are classified as harmful substances. There are several groups of PAH commonly used. PAH_{16} consists of 16 substances of which some are considered more and some less harmful. In some cases PAH_4 is used instead, which consists of only 4 substances. In this scenario an annual quantity of ~0,13 t of PAH_{16}:s could enter GOF via wash water, of which ~50% would naphthalene, which has a separate EQS value. PAH_4 emissions to air are regularly monitored in Finland, quantities entering water are more uncertain. Largest PAH source in Finland is energy and heat production, with emissions of more than 10t/a in 2003. The total emissions to air from Finland were that year 16,7t. (Suomen Ympäristökeskus, 2006)

Environmental quality standards (EQS) set a limit for acceptable quantities of PAH in GOF. For naphthalene it is 2 µg/kg, for other PAH it is given as the quantity of bentso(a)pyrene, which is 0,27 µg/kg. (FINLEX 23.11.2006/1022 annex 1) In the wash water the quantity is 0,01µg/l, but the background concentration was unknown. This value is still well below the limit for acceptable sea water concentration. With this bentso(a)pyrene concentration wash waters would not cause changes in the total concentration in GOF.

For naphthalene the results are similar. Total emissions would make ~0,03% of the EQS value of 2 µg/kg in a year (FINLEX 23.11.2006/1022 annex 1). Therefore, the changes would not be relevant because of water mixing.

9.5 COD

Chemical oxygen demand (COD) is a value that describes the amount of that oxygen will be depleted from the receiving water body. In Baltic Sea oxygen depletion is an existing issue especially in the deep basins of Baltic Proper. When all oxygen is depleted bacteria start using anaerobic processes, producing hydrogen sulphide, which is toxic to marine life. (Viktorsson, 2017)

In wash water the main substance increasing COD is SO_x compounds that ionize and then oxidize as described in 4.2.1. In this scenario annual COD would be 1074 t/a. That can be compared to the biological oxygen demand of riverine input to Gulf of Bothnia, which is ~600 000 t/a (Ahl, 1997). Biochemical oxygen demand describes the amount of oxygen consumed by organisms in order to process the organic compounds in the water sample. No data for COD or BOD riverine input to GOF was available, but value for Gulf of Bothnia can be used to give an overview, since total riverine runoff quantities of these areas are relatively close. The quantity in wash water is also below the Finnish limits for general waste water.

10 Conclusion

Open loop scrubbers are a cost-efficient way to comply with sulphur emission limits. As long as the acceptable emission levels are can be met, open loop scrubbers can be used in the GOF. The low water alkalinity in the eastern parts may cause difficulties in accomplishing acceptable sulphur levels in exhaust gas, so a possibility to add NaOH to the open loop circulation may be necessary.

In this study scenario the total emissions from open loop systems were calculated for the total consumption of IMO vessels´ main engines. The main additional emissions to water were sulphur oxides, nickel and vanadium. Other emissions discussed earlier would be similar also when using low sulphur fuels. In this case the emissions would first enter atmosphere and then later on partially Baltic Sea.

The sulphur oxides had naturally the largest quantity, but it is also the most common in sea water and therefore not a risk to marine environment. Nickel and vanadium had relatively low total quantities. The possible nickel input was compared with AA-EQS value and was found to have no relevant affect to the total concentration. Vanadium had a slightly higher total input, but it is not considered harmful to environment, and therefore limit value does not exist in Finland.

Other issue discussed was the possible affect on the acidification of GOF, since the open loop wash water has a low pH. Total excess of hydrogen ions was compared with the neutralization capacity of the annual riverine input water, and only one percent was needed for the wash water neutralization. Even in much larger quantities wash water would not have significant affect, since the main cause of acidification is the growing CO_2 concentration in the atmosphere and water.

The overall results show that the possible impact on marine environment is so marginal, that with the growing ship traffic and emissions the use of open loop systems would still be acceptable. WWF has predicted the ship traffic would double from the level of year 2010 to 2030. Even with these numbers, use of open loop scrubbers would not cause an issue to the marine environment.

11 Emission reduction with closed loop scrubber

While open loop systems can be safely used in Gulf of Finland, closed loop systems give a possibility for even further emission reductions. The water quantities used in closed loop systems are much lower, ~20 m^3/MWh, which allows for more affective bled of water treatment. Sodium hydroxide does not cause a threat to the environment, and the neutralizing of wash water also removes the possible effect on acidification (Hellenic Petroleum, 2019). (Jesper Kjølholt, 2012)

In test onboard MT Suula sludge and bled off water has been tested. The results show, that the efficient wash water cleaning has been able to reduce metals in the bled off water by 66

– 83%. For PAH the reduction was 97-98% and for Hydrocarbons nearly 100%. Since sludge production is only ~0,1-0,4 kg/MWh sludge can be easily stored onboard for disposal to shore facilities. (Wärtsilä, 2010)

Even tough wash water treatment is available and used in some open loop systems, the results are not as good. The large water quantities cause difficulties for the cleaning systems, but some sludge can still be collected.

12 Limitations

This evaluation of environmental impact was partly based on the wash water test results from Ficaria Seaways, since they were the only available test data that had all the necessary data for this study. Even if there were likely some unreliable results in the data the results showed most likely too large quantities for several substances, not too small. For more accurate evaluation more tests would be needed from different vessels using different open loop systems, since even though the basic principle of open loop scrubbers is the same, there are large differences in the constructions that may affect the quality of wash water.

The tests onboard Ficaria Seaways were done in the English Channel and therefore in saltier water with higher alkalinity. For more accurate information regarding the emissions in GOF test should be done in the eastern GOF in the almost fresh water. This should have an effect on the necessary wash water usage for required cleaning result, however this wouldn´t likely affect the total emissions to water.

The use of water cleaning unit such as hydro cyclone with post processing should have a clear effect on the wash water quality, so the amount solid particles in the wash water are likely much greater in systems without any wash water cleaning. Wash water cleaning is not a requirement for open loop scrubbers if the limit values are met. Accurate wash water sampling should be completed in systems with and without wash water cleaning unit to be able to make conclusions on the benefits of water cleaning and emissions for amount of fuel used.

This study only evaluates the overall impact in open waters, assuming that the emissions spread evenly in the study area. For most parts this is quite accurate, since most ships use the traffic separation schemes in the middle of GOF. Open loop scrubbers may have a negative impact in confined waters such as ports with limited water exchange and voluminous traffic. At the moment many vessels only use scrubbers for main engines, and therefore the scrubbers aren't used in port. If scrubbers are used in ports for prolonged time, it may have a local impact on water quality.

Inert gas systems used onboard tankers are used in ports, and work using open loop scrubbing principle. Even though these systems use much smaller quantities of fuel, in cases were the water exchange is really limited, and ship traffic is dense, it may be necessary to monitor the water quality. Same applies if scrubbers became common for auxiliary engines.

13 Literature

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